EDR,
respiratory signal
apnea detection

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COMPARING METHODS OF ECG RESPIRATION SIGNALS DERIVATION BASED ON MEASURING THE AMPLITUDE OF QRS COMPLEXES

This paper presents the study of algorithms for derivation of respiration waveform from the electrocardiogram. The problem has considerable clinical impact, because the heart rate and respiration are both driven by the central nervous system, and commonly used low-cost Holter recording may be used for efficient detection of breath disturbances (e.g. apnea). Three methods based on: heart rate, heart position and lung resistance influencing the ECG amplitude were compared in our research. Among 18 volunteers breathing at a controlled frequency all implemented algorithms show acceptable sensitivity of order of 97% in slow breathing phases detection. In fast breathing the sensitivity is reduced to 90%, since the heart beats are too sparse with regard of respiration waveform.

1. INTRODUCTION

ECG is the most accessible and the most commonly used electrodiagnostic method. Information included in the ECG signal concerns not only the heart function but also other systems, especially the respiratory one.

The respiration measurement is significant in many cases. Kussmaul respiration in metabolic acidosis is especially important for patients treated in intensive care warms as well as Cheyene–Stokes respiration in the case of tissue anoxaemia.

Moreover, the respiration monitoring is the basis of the sleep apnea syndrome diagnostics, and the latest research indicates the correlation of the respiratory system dysfunction with the high risk factor in circulation system diseases.

The applied methods of respiration measurement are less accessible and more expensive than the ECG. Most of them require the conscious cooperation of patients or their hospitalisation and monitoring. Besides, the application of additional measuring elements to a patient in a bad condition is unnecessary pressure.

Due to the above mentioned reasons, receiving information about respiration on the basis of the ECG signal can be very useful. It especially refers to the diagnosis of the sleep apnea syndrome based on the ECG signal received by Holter technique. Because of this, in recent years the growing interest in the method can be noticed all over the world [1-6].

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The comparative analysis of respiratory derivation methods based on the electrocardiogram is presented in the article. These methods have been verified on the bases of ECG signals registered for a group of people chosen at random.

2. MATERIALS AND METHODS

2.1. THEORETICAL PRINCIPLES OF THE IMPLEMENTED METHODS

During respiration some changes in the chest volume can be observed. Electrodes placed on a patient's chest move away from the heart during an inspiration and move nearer during an expiration. These changes of measurement conditions are represented in the amplitude of the signal measured by chest leads.

To derive the respiratory signal, the maximum value of the amplitude of QRS complexes is used at the peak of R-wave. However, the respiratory signal received by these methods is disturbed and its filtration is necessary.

The above mentioned methods have been described by Travaglini et al. [6].

Furthermore, some changes of the direction of the main cardiac electrical axis may be noticed. It is the result of the change in the heart position inside the chest when the diaphragm lowers during an inspiration. The method of the axis measurement has been presented by G.B. Moody et al. in the [5].

The direction of the axis can be estimated approximately by the ratio of the amplitudes of QRS complexes into the orthogonal leads: I and aVF. In this article the axis is determined as:

$$arctg\frac{|A_I|}{|A_{aVF}|} \tag{1}$$

2.2. THE DERIVATION AND THE ANALYSIS OF RESPIRATORY SIGNALS

A series of experiments has been carried out on 18 volunteers selected at random. The 12-lead ECG signals were registered for each person, the first five measurements with precise frequency of breathing imposed by a metronome: 8, 10, 15, 20 and 25 breaths per minute and one more additional signal while breathing freely. During the last measurement, the patient performed a deep inspiration and a deep expiration, and stopped breathing for 20 seconds.

The electrocardiograph with sampling frequency of 400 Hz was used to measure the signals. Their frequency proved to be suitable to do the analysis.

The QRS complexes were detected in each signal and the amplitude of R-waves being the average of 5 points around the maximum was received. These factors defined the respiration waveforms.

The signals coming directly from the aVR and V1 leads, sums of signals from V1 and V2, V3 and V4, V5 and V6 leads, and arctangent of the ratio I/aVF were selected for further more detailed analysis. Both linear and splines interpolation, were performed in order to uniformize the respiration sampling.

Figure 1 shows the linear and splines interpolation.

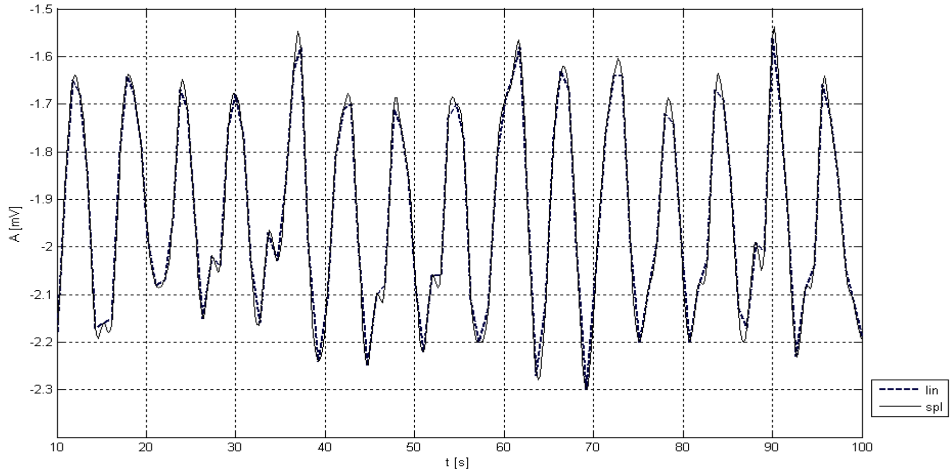

Fig.1. Linear (lin) and splines (spl) interpolation.

The respiration waveforms were then analysed with use of FFT (Fast Fourier Transform).

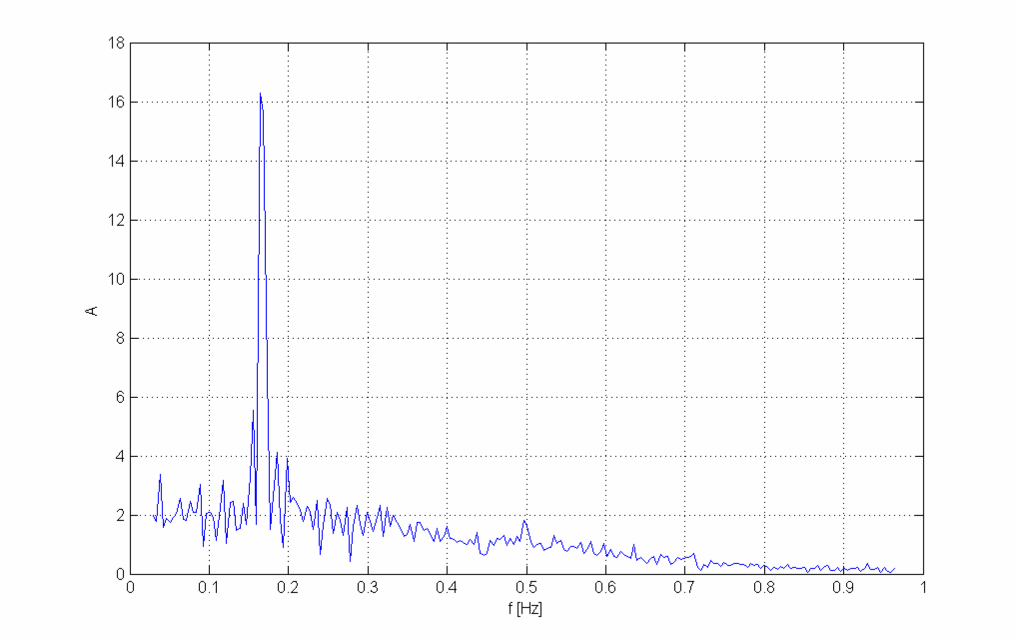

Fig.2. Sample spectrum of calculated respiration waveform

Fourier's analyses were used to estimate the correctness of the respiration waveforms received and to define the parameters of the filter (fig.2.).

High pass filter based on IFFT (Inverse Fast Fourier Transform) was used for filtration. Cut-off frequency was set to 0,1 Hz. Figures 3 and 4 show the EDR signals before (org) and after (fil) filtration.

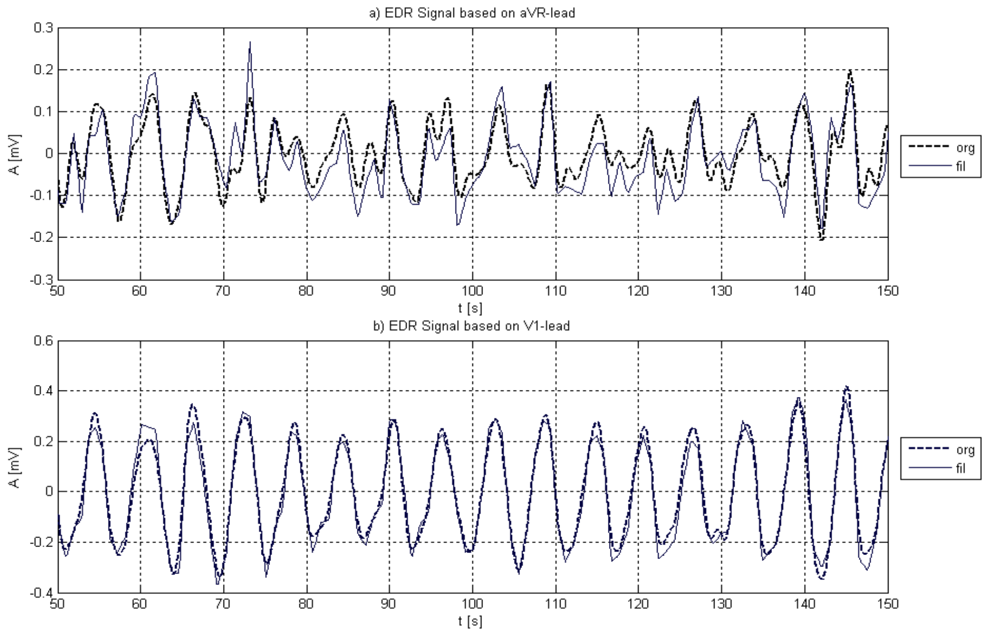

Fig.3. EDR Signals based on aVR (a) and V1 (b) leads for respiration frequency 10 per minute.

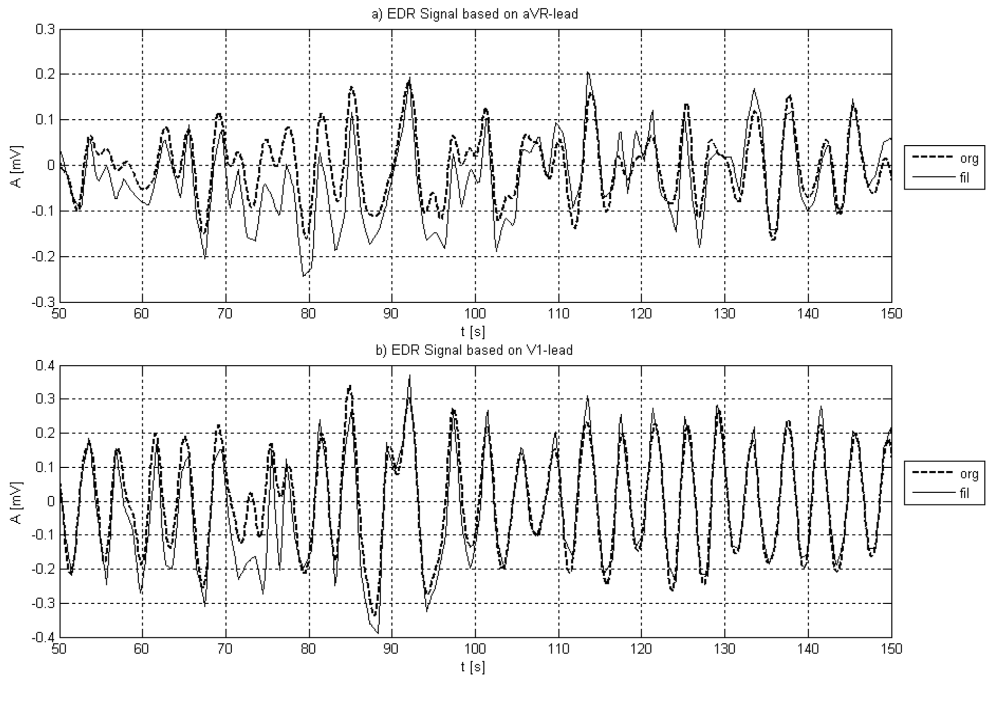

Fig.4. EDR Signals based on aVR (a) and V1 (b) leads for respiration frequency 15 per minute.

The analysis of the changes in breathing frequency in time was also done with the help of Short-Time Fourier's Transform. Some factors to assess the applied signal derivation methods were suggested and used to compare their effectiveness.

3. VALIDATION METHODS OF THE EDR SIGNAL

The derived respiration signals were visually analysed. The shape and the course of the signals were estimated as well as the extent of disturbances. The automatic analysis was also carried out and the following factors were suggested for assessment:

1. The number of breaths in definite time period with comparing them with the theoretical value expected for the signal.
2. The mean time sections between the following inspirations and the following expirations.
3. The standard deviation of these values
4. The dominant frequency of the signal during the WFT analysis with comparing it with the value required.
5. The deviation of dominant frequencies shown in each fixed measuring window.
6. The calculation of the ratio of the peak amplitude for the dominant frequency to the mean value of the amplitude in the examined frequency interval.

4. RESULTS

Each tested person showed high consistence of respiratory cycles included in the EDR signal with the theoretical value expected for a given signal.

Table 1 contains the results of the visual analysis of EDR signals. The percentage of the signals consistent with the real course of respiratory cycles was calculated for each respiration frequency trial. In the last line the proportional consistence of experimental and theoretical data for a given method was shown.

Table1. The results of the visual analysis of EDR signals

METHOD► RESPIRATION▼	aVR	V_1	V_1+V_2	V_3+V_4	V_5+V_6	arctg	SUM	%
	counts of cycled fund as consistent per 18 patients							
8	18	17	18	17	16	17	139	97%
10	16	17	18	18	15	18	138	96%
15	15	16	17	16	13	18	129	90%
20	16	17	16	17	15	18	131	91%
25	12	13	14	16	13	14	110	76%
SUM	77	80	83	84	72	85	-	-
%	86%	89%	92%	93%	80%	94%	-	-

Automatically calculated factors assessing the effectiveness of the methods were presented in table 2.

Table 2. Factors assessing the effectiveness of the methods.

	aVR	V_1	V_1+V_2	V_3+V_4	V_5+V_6	arctg
p	**3,096**	**4,247**	**3,990**	**3,919**	**3,310**	**4,331**
std	0,732	1,120	1,070	1,096	0,732	1,305
stdp	**0,589**	**0,883**	**0,791**	**0,732**	**0,618**	**0,766**
std	0,263	0,447	0,366	0,387	0,327	0,363
wd [s]	**1,586**	**1,126**	**1,226**	**1,367**	**1,569**	**1,127**
std	0,457	0,587	0,601	0,549	0,605	0,591
wy [s]	**1,669**	**1,146**	**1,261**	**1,369**	**1,510**	**1,113**
std	0,514	0,681	0,669	0,513	0,506	0,512
f [Hz]	**0,053**	**0,032**	**0,038**	**0,043**	**0,046**	**0,034**
std	0,034	0,034	0,034	0,038	0,031	0,033

The factor “p” is the ratio of the peak amplitude for the dominant frequency to the mean value of the amplitude in the examined frequency interval. The “stdp” represents the deviation of these values. The “wd” and “wy” are the deviations of mean time sections between the following inspirations (“wd”) and following expirations (“wy”). The “f” is the deviation of dominant frequencies of the signals during the WFT analysis with comparing its with the value required. Finally, the “std” stand for the standard deviation of calculated values.

For each patient a free respiration period ECG was registered. After about 100 seconds of the measurement the patient performed a deep inspiration and a deep expiration, and 50 seconds later, he stopped breathing for 20 seconds simulating apnea. After the ECG respiratory signal derivation, in 96% of patients changes in the signal were observed, representing a deep inspiration and expiration, and no changes occurred in the deflexion of the curve as a response for stopping respiration. The sum of the V1 and V2 amplitudes and the changes in the direction of the mean cardiac electrical axis yield best results.

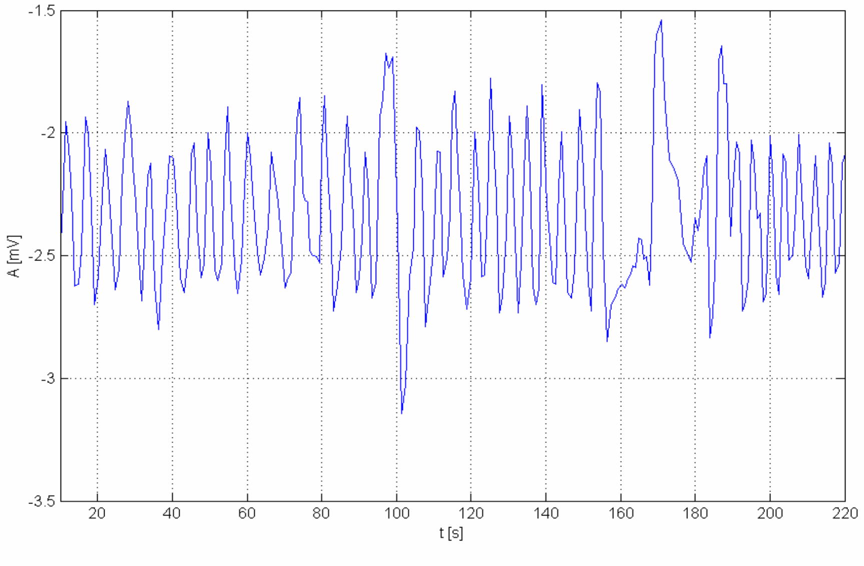

Fig.5. EDR Signal based on the sum of V1 and V2 leads.

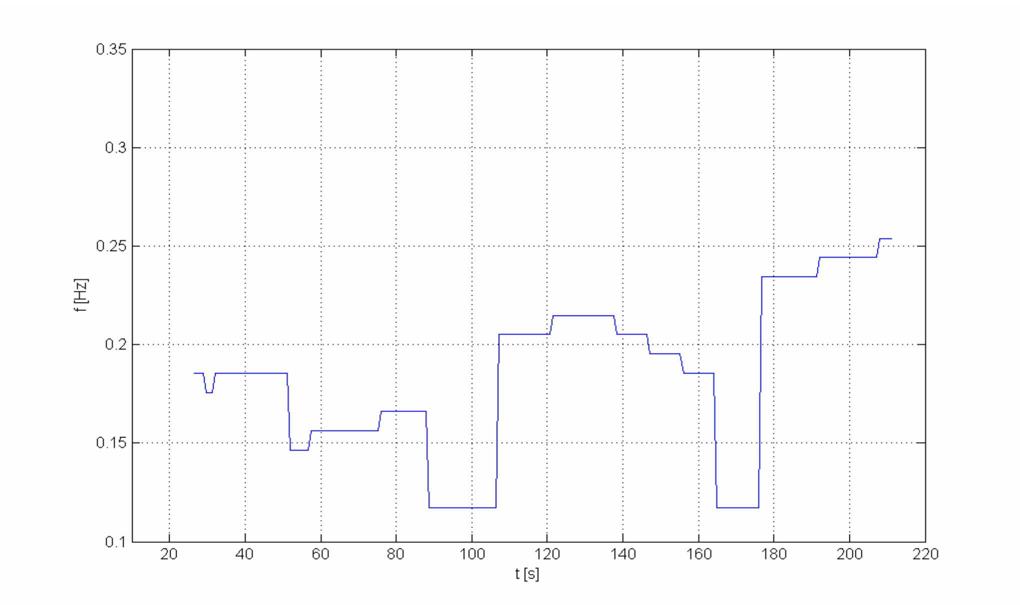

Fig.6. Frequency and time domain analysis of EDR Signal based on on the sum of V1 and V2 leads.

Figure 5 shows the respiratory signal derived by the method based on the sum of V1 and V2 signals and its frequency and time domain analysis (figure 6).

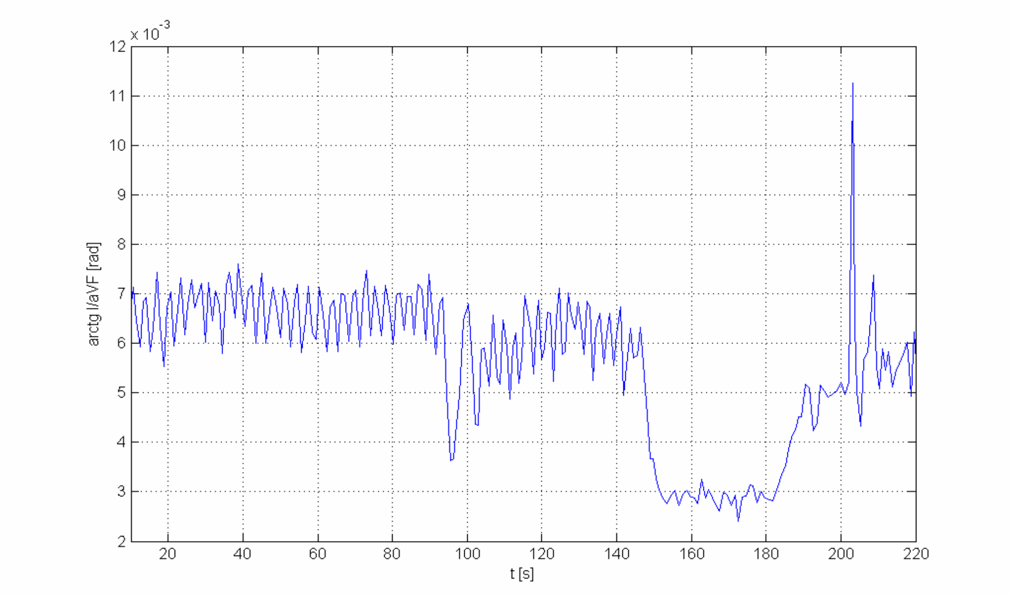

Fig.7. EDR Signal based on changes in the direction of the mean cardiac electrical axis.

Figure 7 shows the respiratory signal derived by the method based on changes in the direction of the mean cardiac electrical axis and its frequency and time domain analysis (Figure 8).

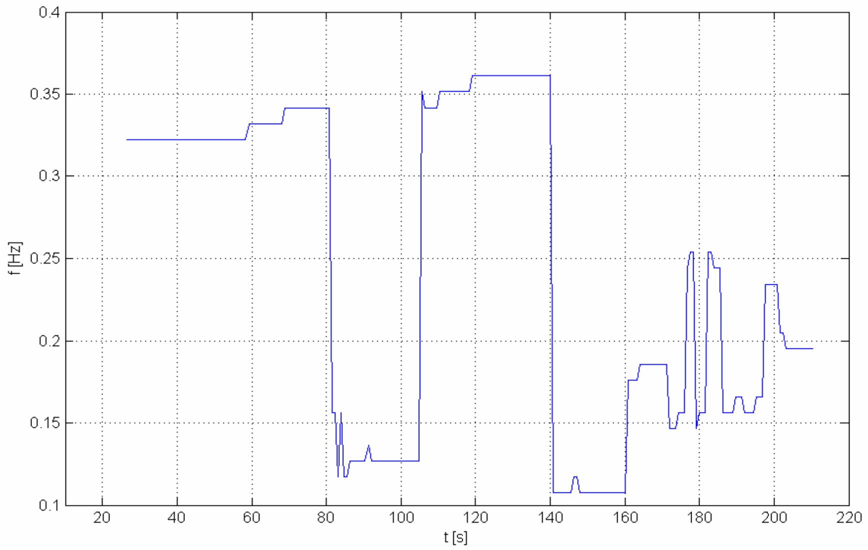

Fig.8. Frequency and time domain analysis of EDR Signal based on the based on changes in the direction of the mean cardiac electrical axis.

5. CONCLUSIONS

In this work we present comparing methods of ECG Respiration Signal Derivation based on measuring the amplitude of QRS complexes. Our conclusions are:

- The results presented in the research work prove that the methods applied in the ECG respiration signal derivation are correct and effective.
- The respiration signal derived on the basis of the V1 and V1+V2 leads includes the fewest number of disturbances.
- Among all methods applied, the signal derived from aVR lead include the greatest number of disturbances. The reason is that the limb leads doesn't provide information of respiratory chest motion.
- High pass filter based on Inverse Fast Fourier's Transform can be used in filtration of the signal.
- The amplitude of respiratory signals reflects the depth of an inspiration and expiration.
- All studied methods allow reliable detecting of simulated apnea.
- All methods applied helped to derive respiration signals consistent, according to the respiration frequency, with the theoretical value expected for a given signal.

In the near future further validation on a larger patient group with sleep apnea syndrome is planned.

6. ACKNOWLEDGEMENTS

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